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Date of Filing	:	31 AUGUST 2001
Application Number	:	200105345-3
Applicant(s) / Proprietor(s) of Patent	:	NANYANG TECHNOLOGICAL UNIVERSITY
Title of Invention	:	METHOD AND APPARATUS FOR ENHANCING THE SOUND QUALITY OF AN ULTRASONIC LOUDSPEAKER SYSTEM

SERENE CHAN (Ms)
Assistant Registrar
for REGISTRAR OF PATENTS
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SINGAPORE
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(CHAPTER 221)
PATENTS RULES

Rule 19

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200105345-3

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REQUEST FOR THE GRANT OF A PATENT

THE GRANT OF A PATENT IS REQUESTED BY THE UNDERSIGNED ON THE BASIS OF THE PRESENT APPLICATION

I. Title of Invention	**METHOD AND APPARATUS FOR ENHANCING THE SOUND QUALITY OF AN ULTRASONIC LOUDSPEAKER SYSTEM**	
II. Applicant(s) *(See note 2)*	(a) Name	**Nanyang Technological University**
	Body Description/ Residency	A body corporate formed pursuant to the Nanyang Technological University Act Cap. 192
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	State	
	Country	
	(c) Name	
	Body Description/ Residency	
	Street Name & Number	
	City	
	State	
	Country	

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III. Declaration of Priority *(see note 3)*	Country/Country Designated		File No.	
	Filing Date			
	Country/Country Designated		File No.	
	Filing Date			
	Country/Country Designated		File No.	
	Filing Date			
IV. Inventors *(see note 4)*				
(a) the applicant(s) is/are the sole/joint inventor(s)	☐ Yes		☒ No	
(b) A statement on Patents Form 8 is/will be furnished.	☒ Yes		☐ No	
V. Name of Agent (if any) *(See note 5)*	**ALLEN & GLEDHILL**			
VI. Address for Service *(See note 6)*	Block/Hse No.	36	Level No.	18
	Unit No./PO Box	01	Postal Code	068877
	Street Name	**ROBINSON ROAD**		
	Building Name	**CITY HOUSE**		
VII. Claiming an earlier filing date under Section 20(3), 26(6) or 47(4). *(See note 7)*	Application No.			
	Filing Date			
	[Please tick in the relevant space provided]: ( ) Proceeding under rule 27(1)(a). Date on which the earlier application was amended = ________ or ( ) Proceeding under rule 27(1)(b).			

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<table>
<tr><td>VIII. Invention has been displayed at an International Exhibition
(See note 8)</td><td>☐ Yes ☒ No</td></tr>
<tr><td>IX. Section 114 requirements
(See note 9)</td><td>The invention relates to and/or used a micro-organism deposited for the purposes of disclosure in accordance with Section 114 with a depository authority under the Budapest Treaty
☐ Yes ☒ No</td></tr>
<tr><td>X. Check List
(To be filled in by applicant or agent)</td><td>A. The application contains the following number of sheet(s):-
1. Request — 4 Sheets
2. Description — 11 Sheets
3. Claim(s) — 5 Sheets
4. Drawing(s) — 5 Sheets
5. Abstract — 1 Sheets

B. The application as filed is accompanied by:-
1. Priority document ☐
2. Translation of priority document ☐
3. Statement of Inventorship & right to grant X
4. International Exhibition certificate ☐</td></tr>
<tr><td>XI. Signature(s)
(See note 10)</td><td>Applicant (a): [signature]
Date: 31 August 2001
Applicant (b):
Date:
Applicant (c):
Date:</td></tr>
</table>

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NOTES:

1. This form when completed, should be brought or sent to the Registry of Patents together with the prescribed fee and 3 copies of the description of the invention, and of any drawings.

2. Enter the name and address of each applicant in the spaces provided at paragraph II. Names of individuals should be indicated in full and the surname or family name should be underlined. The names of all partners in a firm must be given in full. The place of residence of each individual should also be furnished in the space provided. Bodies corporate should be designated by their corporate name and country of incorporation and, where appropriate, the state of incorporation within that country should be entered where provided. Where more than 3 applicants are to be named, the names and address of the fourth and any further applicants should be given on a separate sheet attached to this form together with the signature of each of these further applicants.

3. The declaration of priority at paragraph III should state the date of the previous filing, the country in which it was made, and indicate the file number, if available. Where the application relied upon in an International Application or a regional patent application e.g. European patent application, one of the countries designated in that application [being one falling under the Patents (Convention Countries) Order] should be identified and the name of that country should be entered in the space provided.

4. Where the applicant or applicants is/are the sole inventor or the joint inventors, paragraph IV should be completed by marking the "YES" Box in the declaration (a) and the "NO" Box in the alternative statement (b). Where this is not the case, the "NO" Box in declaration (a) should be marked and a statement will be required to be filed on Patents Form 8.

5. If the applicant has appointed an agent to act on his behalf, the agent's name should be indicated in the spaces available at paragraph V.

6. An address for service in Singapore to which all documents may be sent must be stated at paragraph VI. It is recommended that a telephone number be provided if an agent is not appointed.

7. When an application is made by virtue of section 20(3), 26(6) or 47(4), the appropriate section should be identified at paragraph VII and the number of the earlier application or any patent granted thereon identified. Applicants proceeding under section 26(6) should identify which provision in rule 27 they are proceeding under. If the applicants are proceeding under rule 27(1)(a), they should also indicate the date on which the earlier application was amended.

8. Where the applicant wishes an earlier disclosure of the invention by him at an International Exhibition to be disregarded in accordance with section 14(4)(c), then the "YES" Box at paragraph VIII should be marked. Otherwise the "NO" Box should be marked.

9. Where in disclosing the invention the application refers to one or more micro-organisms deposited with a depository authority under the Budapest Treaty, then the "YES" Box at paragraph IX should be marked. Otherwise, the "NO" Box should be marked.

10. Attention is drawn to rules 90 and 105 of the Patent Rules. Where there are more than 3 applicants, see also Note 2 above.

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METHOD AND APPARATUS FOR ENHANCING THE SOUND QUALITY OF AN ULTRASONIC LOUDSPEAKER SYSTEM

INVENTORS:

Woon-Seng Gan, Meng-Hwa Er, Yew-Hin Liew, Furi Andi Karnapi, Chee-Mun Lee

BACKGROUND OF THE INVENTION

Audio signals are normally provided to listeners via an audio path that includes a source (e.g. a CD, tape cassette player, microphone etc.), an amplifier, and an electrodynamic cone-type loudspeaker. More recently, interest has been shown in delivering audio using an ultrasonic carrier wave. In this case, an audio-frequency signal is amplitude-modulated onto the ultrasonic carrier wave. The modulated carrier wave is then provided to an ultrasonic loudspeaker for delivery. Demodulation of the audio-frequency signal either occurs naturally as a result of the interaction of the carrier wave with the transmission medium (normally air, which has non-linear propagation characteristics for ultrasonic waves). Reflection can, for example, take place when the modulated carrier wave encounters an object that absorbs energy at ultrasonic frequencies but reflects energy at audio frequencies.

The advantages of using an ultrasonic carrier wave to deliver audio include the highly directional nature of the modulated ultrasonic wave, the fact that the carrier wave is steerable (for example by providing reflective surfaces), and also that the signal is not audible prior to demodulation. By proper application of these advantages, audio can be delivered to specific locations, from where the audio appears to originate. A general discussion of the transmission of audio signals can be found in European published patent application no. EP 973 152.

However, technical challenges remain in the use of ultrasonic technology for delivering audio. For example, the fidelity of the demodulated audio signal can still be improved. In particular, the delivery of adequate power at low frequencies is a problem.

Human hearing is more sensitive to stimuli having middle frequency components (i.e. 3-4 kHz) than low frequency components (i.e. "bass," below 500 Hz). To perceive

lower frequency sounds at the same loudness as at the middle frequencies, it is necessary to generate higher sound pressure levels at the lower frequency.

SUMMARY OF INVENTION

According to one aspect of the invention, a harmonic generator is used to generate harmonics of the lower frequencies in an audio signal. These harmonics and the audio signal are then modulated onto an ultrasonic carrier wave and are transmitted by ultrasonic emitters to provide (upon demodulation) a psycho-acoustic impression of improved perception at low frequencies. The harmonics can either be combined with the original or otherwise-modified audio signal prior to modulation and transmission, or modulated and/or transmitted separately but simultaneously.

According to another aspect of the invention, the modulated ultrasonic signal is band-passed into two or more different band-limited signals with overlapping/non-overlapping frequency bands at center frequencies of f_1 to f_N respectively. These band-limited signals are then amplified and transmitted by different ultrasonic transducers (or groups of ultrasonic transducers) having mechanical resonance frequencies substantially equal to a characteristic frequency of the band limited signal. Typically, the mechanical resonance frequencies are substantially equal to the center resonant frequencies f_1 to f_N.

According to yet another aspect of the invention, the unmodulated audio signal is bandpassed into two or more different band-limited signals with overlapping/non-overlapping frequency bands. These band-limited signals are then provided to separate ultrasonic modulators that have the same or different carrier frequencies. The resulting modulated signals are then provided to ultrasonic emitters that have mechanical resonant frequencies substantially equal to a characteristic frequency of the modulated signals.

More particularly, according to one embodiment of the invention there is provided a method of processing an audio signal, comprising:

separating a low frequency component from the audio signal;

generating harmonics of the low frequency signal to create a preprocessed signal; and

modulating the preprocessed signal onto an ultrasonic carrier wave.

According to another embodiment of the invention there is provided a method of processing an audio signal comprising the steps of:

modulating the audio signal onto an ultrasonic carrier wave to provide a modulated audio signal;

separating the modulated audio signal into a plurality of band-limited signals; and

transmitting each of the plurality of frequency bands from a separate ultrasonic transmitter.

According to yet another embodiment of the invention there is provided an apparatus for processing an audio signal received from an audio source, comprising:

a first filter to separate a low frequency component from the audio signal;

a harmonics generator to generate harmonics of the low frequency component; and

an ultrasonic modulator to modulate the low frequency component and the harmonics onto an ultrasonic carrier wave.

Also, according to a further embodiment of the invention there is provided an apparatus for processing an audio signal comprising:

a filter bank for separating the audio signal into a plurality of band-limited signals;

a plurality of ultrasonic modulators corresponding to the respective band-limited signals to modulate each of the band-limited signals onto an ultrasonic carrier wave; and

a plurality of ultrasonic emitters for receiving and transmitting the modulated band-limited signals.

Still further, according to one embodiment of the invention there is provided an apparatus for processing an audio signal, comprising:

an ultrasonic modulator to modulate the audio signal onto an ultrasonic carrier wave thereby to create a modulated audio signal;

a filter bank to separate the modulated audio signal into a plurality of band-limited signals. Preferably this apparatus includes a plurality of ultrasonic emitters to transmit the plurality of band-limited signals.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail with reference to the attached figures, in which:

FIG. 1 is a schematic diagram of an ultrasonic system according to one aspect of the invention;

FIG. 2 is a schematic diagram of the bass enhancing module of the system of Fig. 1;

FIG. 3 is a schematic diagram of the preprocessing module of the system of Fig. 1;

FIG. 4 is a schematic diagram of a pre-modulation multiple path ultrasonic system according to one aspect of the invention; and

FIG. 5 is a schematic diagram of a post-modulation multiple path ultrasonic system according to one aspect of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a schematic diagram that shows an exemplary system according to one aspect of the invention. The system, generally identified with the numeral 10, commences with a sound source 12. The sound source 12 may be any apparatus for generating an audio signal for use in the invention, for example a microphone, optical disc player, magnetic tape player, RF receiver, computer system, etc. The sound source 12 may include internal processing of the signal it generates (e.g. amplification, normalization, bias adjustment, equalization, digital to analog conversion, noise reduction etc.) as is known in the art. Also, the sound source 12 may itself include a number of components that perform different functions, and a number of sound sources may together combine to provide the signal.

The sound source 12 is coupled to a bass enhancing processor 14 and optionally to a pre-processor 16. The bass enhancing processor 14, as the name suggests, serves to enhance the signal to provide improved bass perception to the listener. The bass enhancing processor 14 is described in more detail below with reference to Fig. 2. The pre-processor 16 is described in more detail below with reference to Fig. 3. The output from the pre-processor 16 and bass enhancing processor 14 are combined and provided to an ultrasonic modulator 18.

The ultrasonic modulator 18 generates an ultrasonic carrier wave onto which the combined signals from the pre-processor 16 and bass enhancing processor 14 are modulated. The ultrasonic carrier wave has a frequency that is above the audible range of the human ear (e.g. above at least 15 kHz, normally above 20 kHz). The frequency of the carrier signal generated by the ultrasonic modulator 18 may be any suitable frequency, and is typically selected so that all frequency components of the modulated signal are above 20 kHz. As an example only, a frequency of 40 kHz would be appropriate for use in the invention.

Also provided in the system 10 are a driving circuit 20 and one or more ultrasonic emitters 22. The driving circuit 20 provides amplification of the modulated signal received from the ultrasonic modulator 18, and the ultrasonic emitters 22 transmit the modulated signal into the air. The driving circuits 20 and the ultrasonic transmitters 22 are conventional in nature, and their particular configurations (power levels, etc.) will depend on the particular application.

The bass enhancing processor 14 is shown in more detail in Fig. 2. In the exemplary embodiment, the bass enhancing processor includes a filter bank 30 and a low frequency preprocessor 32. The filter bank 30 separates the audio signal received from the audio source 12 into two or more frequency bands. In particular, a signal 34 in a low frequency band (for example less than 500 Hz) is passed to the low frequency preprocessor 32 by providing a low-pass filter in the filter bank 30. The filter bank 30 may be provided with other filters to provide other frequency bands.

The low frequency preprocessor 32 comprises a harmonics generator that generates harmonics of the low frequency signal 34 in a know manner. In particular, the harmonics generator generates a residue harmonic signal having a sequence of harmonics. The sequence of harmonics, generated with respect to each fundamental frequency, contains at least three consecutive harmonics from among the primary set of harmonics for the fundamental frequency.

These harmonics are added to the low frequency signal 36 by the summer 44. The combined signal is then passed to the modulator 18. By adding harmonics of the low frequency signal to the low frequency signal 34, a listener to the signal emitted by the

ultrasonic emitters 22 will (after demodulation), have improved low frequency perception than is the case without this processing. The signal leaving the low frequency preprocessor 32 is passed to an amplifier 38.

Also included in the bass enhancing processor 14 is a loudness analyzer 40. The loudness analyzer 40 measures the perceived loudness of the fundamental low frequency of the sound source 12. According to this measurement, it determines the required amplification/attenuation to apply to the sequence of harmonics generated in the low frequency preprocessor 32. This amplification/attenuation is calculated in order to match the loudness of the fundamental frequency and the perceived loudness of the artificially created harmonics. There are well established procedures in the public literature for realizing loudness analyzers. This field is being extensively studied and improved methods are constantly being suggested. Any suitable loudness analyzer may be utilized in the invention.

The amplifier 39, which receives the low frequency signal 34 from the filter banks 30, amplifies the signal based on a weighting function 42. The weighting function 42 is a function or a constant that determines the amount of the low frequency signal to be summed to the output of the low frequency preprocessor 32. The weighting function is adjusted according to the physical bass response efficiency of the unenhanced system itself. For example, if the bass response of the system is poor, the low frequency signal of interest should preferably be filtered out. On the other hand, if the original system exhibits, in a given bass frequency range, an efficiency that approaches its average efficiency, then preferably a full or attenuated intensity of the original low frequency signal of interest is summed with the signal from the low frequency preprocessor 32.

After being amplified in the amplifiers 38 and 39, the processed signal from the low frequency preprocessor 32 and the low frequency signal 34 are combined in a summer 44. These bass enhanced signals are combined with the output from preprocessor 16 and are passed on to the modulator 18, and from there to the driving circuits 20, and eventually to the ultrasonic emitters 22.

Fig. 3 illustrates the pre-processor 16 of Fig. 1 in more detail. The preprocessor 16 includes a psycho acoustic processor 50, filter banks 52, and an audio preprocessor 54. The

psycho acoustic processor 50 analyzes the input audio signal and computes the amount of noise masking available as a function of frequency. The processor 50 takes advantage of the human auditory system's inability to hear noise under conditions of auditory masking. This masking is a perceptual property of the human auditory system that occurs whenever the presence of a strong audio signal makes a temporal or spectral neighborhood of weaker audio signals imperceptible. Under such conditions, the frequencies that will not be perceived can be removed/masked from the signal without affecting the perceived quality of the signal.

The filter banks 52 contain a bank of bandpass filters, with overlapping passbands which model the auditory system that is human perception. An approach to modeling the auditory system is to consider the periphery as a fourier transform followed by a number of bandpass filters, and to view the function of entire lower auditory system as being a spectrum estimator. These filters banks 52 are also called the 'auditory filters'. The function of the filter banks 52 is to split the signal into plurality of bands, which model the peripheral auditory system. In audio literature, it has been concluded that the ear is primarily a frequency analysis device that can be approximated by bandpass filters, consisting of filters with overlapping frequency bands. There are well-established procedures in the public domain for realizing the filter banks, and accordingly they will not be discussed further here.

The audio preprocessor 54 pre-distorts the signal before sending out to the modulator 84. This is typically done to take account of the way in which the ultrasonic signal demodulates in air. One of possible ways to pre-distort is to take the square root of the signal, as proposed in "Audio Application of the Parametric Array," J. Acoust. Soc. Am., Vol 102 pp 3106(A), 1997, J. Blackstock . Another way is to perform the modified square root method as proposed in a patent application entitled: "Method And Apparatus For Generating Directional Sound Using An Ultrasonic Carrier Wave," filed on the same day as this application, the disclosure of which is incorporated herein by reference as if explicitly set forth. In this way, after the self-demodulation process in the air, the resulting distortion of the audio is reduced or minimized.

As can be seen from Fig. 3, the audio signal from the sound source 12 is provided to the filter banks 52 and the psycho acoustic processor 50. After the audio signal passes through the filter banks 52, it is processed further in the audio preprocessor 54. After leaving the audio preprocessor 54, the signal is passed to the modulator 18.

FIG. 4 shows a multiple-path ultrasonic system 60 according to one embodiment of the invention. In this embodiment, the audio signal is split into at least two frequency bands. With this approach, the efficiency of the system may be increased, and the dependency on a particular ultrasonic emitter's bandwidth may be reduced. Using this method, the ultrasonic emitters can be selected to according to their suitability to transmit a particular band of frequencies. Further, by assigning the different frequency bands to the different modulators, it is possible to modulate the signal at different carrier frequencies, which can provide improved matching of the modulated signals to the different ultrasonic emitters.

As can be seen from the figure, the system 60 includes a filter bank 62, a plurality (1 – N) of preprocessors 64, a corresponding plurality (1 – N) of modulators 66, a corresponding plurality (1 – N) of driving circuits 68 and a plurality (1 – N) of ultrasonic emitters 70 (or groups of ultrasonic emitters 70).

The filter bank 62 comprises a number of filters having overlapping or non-overlapping frequency pass bands. Typically, the pass bands are centered at frequencies f_1 to f_N, but the first filter may be a low pass filter and the Nth filter may be a high pass filter. The filter bank 62 divides the signal from the sound source 12 into N signals having frequencies centered at the corresponding frequencies f_1 to f_N of the filters in the filter band.

The preprocessors 72 preprocess each of the N signals. One of the processors 64 may be the bass enhancing processor 14 of Fig. 1, to enhance a low frequency part of the signal but this is not required. The preprocessors 72 may also be the preprocessor 16 of Fig. 1, or may utilize any other preprocessing method to manipulate the signals from the filter bank 62. In another embodiment, the preprocessors 72 may only be provided for selected frequency bands (e.g. for bass enhancement), or may be omitted entirely.

The plurality of modulators 66 modulate the signals received from the preprocessors 64 onto ultrasonic carrier waves. The modulators 66 may use the same carrier frequency, but preferably use carrier frequencies that are chosen to correspond to the frequency characteristics of the signal f_N or to the characteristics of the corresponding ultrasonic emitter 70. Preferably, the frequency of the carrier wave of the modulator 66 is typically matched to the resonant frequency of the corresponding ultrasonic emitter. By way of example only, the signal from the sound source 12 may be split into three different frequency bands at 0-600 Hz, 600 – 4 kHz and 4 –16 kHz, which are modulated using carrier frequencies of 40, 50 and 60 kHz respectively. These modulated signals will in turn be transmitted to ultrasonic emitters having resonant frequencies of 40, 50 and 60 kHz respectively. The proposed system will increase the efficiency of the demodulated audio output. In addition, emitters of high power could be selected to transmit the lower frequency signal f_1 which will boost the bass of the demodulated audio.

The driving circuits 68 receive the modulated signals from the modulators 66, amplify them, and provide them to the ultrasonic emitters 70.

As mentioned, the 1 to N ultrasonic emitters 70, which receive the amplified and modulated signals, are selected to match (as far as possible) the characteristics of the 1 to N signals. Preferably, the resonant frequencies of the ultrasonic emitters are selected to be approximately equal to a characteristic frequency of the signal. In particular, the resonant frequency each of the ultrasonic emitters may be matched to the carrier wave frequency provided by the corresponding modulator 66 to which the ultrasonic emitter is coupled, as described above.

FIG. 5 shows an alternative multiple-path ultrasonic system 80. As with the embodiment of Fig. 4, the audio signal from the audio source 12 is split into at least two frequency bands. In this embodiment however, the signal is split later in the signal path (after modulation) than the embodiment of Fig. 4. As for the previous embodiment, the embodiment of Fig. 5 provides increased efficiency, and the dependency on a particular ultrasonic emitter's bandwidth will be reduced. Using this method, the ultrasonic emitters can be selected to according to their suitability to transmit a particular band of frequencies.

As can be seen from the figure, the system 80 includes a preprocessor 82, a modulator 84, a filter bank 86 comprising a plurality of band pass filters (1 – N), a corresponding plurality (1 – N) of driving circuits 88 and a plurality (1 – N) of ultrasonic emitters 90 (or groups of ultrasonic emitters 70).

The preprocessor 82 preprocesses the signal from the audio source 12. The preprocessor may utilize any preprocessing method, but it is preferably the preprocessor of Fig. 2.

The modulator 84 modulates the signal received from the preprocessor 82 onto an ultrasonic carrier wave, and passes the modulated signal on to the filter bank 86.

The filter bank 86 comprises a number of filters having overlapping or non-overlapping frequency pass bands. Typically, the pass bands are centered at frequencies f_1 to f_N, but the first filter may be a low pass filter and the Nth filter may be a high pass filter. The filter bank 86 divides the signal from the modulator 84 into N signals having frequencies centered at the corresponding frequencies f_1 to f_N of the filters in the filter band. Although the signal passed to the filter 86 is based on a carrier wave having a characteristic carrier frequency, the signal has different frequency components because of the fact that the carrier wave has been modulated by the audio signal from the audio source.

So, for example, if an audio signal with a frequency range of 50 - 16,000 Hz is modulated onto a carrier wave having a frequency of 40kHz, the resulting modulated signal will have a frequency range of approximately 24 - 56 kHz. The filter bank could then, for example, comprise four filters having frequency bands of 23 to 33 kHz, 31 to 41kHz, 39 to 49 kHz and 47 to 57 kHz, with the centers of the frequency bands respectively being 28, 36, 44 and 52 kHz, which will cover the entire frequency range the modulated signal.

The driving circuits 88 receive the modulated signals f_1 to f_N from the filter bank 86, amplify them, and provide them to the ultrasonic emitters 90.

The 1 to N ultrasonic emitters 90 receive the amplified modulated signals from the driving circuits 88, and transmit them. The ultrasonic emitters 90 are selected to match (as far as possible) the characteristics of the 1 to N signals. In particular, the resonant

frequencies of the ultrasonic emitters are selected to be approximately equal to a characteristic frequency of the signal. In the system of Fig. 5, the resonant frequencies of the ultrasonic transmitters 90 are matched to the center frequencies of the corresponding filters in the filter bank 86. So, using the four exemplary filters discussed above, the ultrasonic emitters would have resonant frequencies approximately equal to 28, 36, 44 and 52 kHz. Note that in most cases, each ultrasonic emitter 90 is made up of a group of ultrasonic emitters, and the term ultrasonic emitter thus includes both a single ultrasonic emitter as well as a group of ultrasonic transmitters.

While this invention has been described in terms of several embodiments, it is contemplated that alterations, modifications and permutations thereof will become apparent to those skilled in the art upon a reading of the specification and study of the drawings. For example, a large variety of different target and prize images, screens, fields, and other zones which affect game play can be displayed by the video screen and be moved or changed during game play in various manners. Also, a variety of mechanisms can be used to position the device over a location of the displayed target area, to lower the head toward the screen, and to provide an award to the player.

It is therefore intended that the following claims include all such alterations, modifications and permutations as fall within the spirit and scope of the present invention.

CLAIMS

What is claimed is:

1. A method of processing an audio signal, comprising:

separating a low frequency component from the audio signal;

generating harmonics of the low frequency component to create a preprocessed signal; and

modulating the preprocessed signal onto an ultrasonic carrier wave.

2. The method of claim 1 further comprising the step of:

combining the low frequency component with the preprocessed signal prior to the modulating step.

3. The method of claim 2 further comprising the step of:

combining other frequency components of the audio signal with the preprocessed signal prior the modulating step.

4. The method of claim 3 further comprising the step of:

processing the other frequency components of the audio signal using a psycho acoustic model prior to combining the other frequency components of the audio signal with the preprocessed signal.

5. The method of claim 2 further comprising the steps of:

transmitting the preprocessed signal from a first ultrasonic emitter after the modulation step.

6. The method of claim 5 further comprising the step of:

modulating other frequency components of the audio signal onto an ultrasonic carrier wave; and

transmitting the modulated other frequency components of the audio signal using the first ultrasonic transmitter or a second ultrasonic emitter.

7. The method of claim 6 wherein the preprocessed signal is modulated using an ultrasonic carrier wave having a first frequency and the other frequency components are modulated using an ultrasonic carrier wave having a different, second frequency.

8. The method of claim 7 wherein the first ultrasonic emitter is matched to the first frequency and the second ultrasonic emitter is matched to the second frequency.

9. A method of processing an audio signal comprising the steps of:

separating the audio signal into a plurality of band-limited signals;

modulating each of the band-limited signals onto ultrasonic carrier waves having either the same or different carrier frequencies thereby to create a plurality of modulated signals; and

transmitting each of the modulated signals from separate ultrasonic emitters.

10. The method of claim 9 wherein each of the separate ultrasonic emitters have resonant frequencies that are matched to the frequencies of the respective ultrasonic carrier waves.

11. The method of claim 10 further comprising the step of:

preprocessing at least one of the band-limited signals prior to the modulating step.

12. The method of claim 11 wherein the preprocessing step comprises the steps of:

generating harmonics of the at least one band-limited signal;

combining the harmonics with the at least one band-limited signal.

13. A method of processing an audio signal comprising the steps of:

modulating the audio signal onto an ultrasonic carrier wave to provide a modulated audio signal;

separating the modulated audio signal into a plurality of band-limited signals; and

transmitting each of the plurality of band-limited signals from separate ultrasonic transmitters.

14. The method of claim 13 wherein the ultrasonic transmitters are matched to a corresponding characteristic frequency of the respective band-limited signals.

15. The method of claim 13 wherein the separating step is conducted by passing the audio signal through N filter banks having passbands centered at frequencies f_1 to f_N, and the band-limited signals are transmitted from N ultrasonic transmitters having mechanical resonance frequencies equal to f_1 to f_N respectively.

16. An apparatus for processing an audio signal received from an audio source to generate a bass-enhanced signal, comprising:

a filter to separate a low frequency component from the audio signal;

a harmonics generator to generate harmonics of the low frequency component; and

an ultrasonic modulator to modulate the low frequency component and the harmonics onto an ultrasonic carrier wave.

17. The apparatus of claim 16 further comprising:

a loudness analyzer to determine an amplification level for the harmonics based on the loudness of the audio signal.

18. The apparatus of claim 16 further comprising:

a weighting module to determine an amplification or attenuation level for a low frequency component of interest to be included in the bass enhanced signal.

19. An apparatus for processing an audio signal comprising:

CLMS

a filter bank for separating the audio signal into a plurality of band-limited signals;

a plurality of ultrasonic modulators corresponding to the respective band-limited signals to modulate each of the band-limited signals onto an ultrasonic carrier wave; and

a plurality of ultrasonic emitters for receiving and transmitting the modulated band-limited signals.

20. The apparatus of claim 19 wherein each ultrasonic emitter is matched to a characteristic frequency of the modulated band-limited signal transmitted thereby.

21. The apparatus of claim 20 wherein each ultrasonic emitter has a mechanical resonance frequency that is matched to a characteristic frequency of the modulated band-limited signal transmitted thereby.

22. The apparatus of claim 21 wherein the characteristic frequency is the respective frequency of the carrier wave onto which each of the band-limited signals is modulated.

23. An apparatus for processing an audio signal, comprising:

an ultrasonic modulator to modulate the audio signal onto an ultrasonic carrier wave thereby to create a modulated audio signal;

a filter bank to separate the modulated audio signal into a plurality of band-limited signals.

24. The apparatus of claim 23 further comprising:

a plurality of ultrasonic emitters to transmit the plurality of band-limited signals.

25. The apparatus of claim 24 wherein each ultrasonic transmitter is matched to a characteristic frequency of the band-limited signal transmitted thereby.

26. The apparatus of claim 24 wherein the ultrasonic transmitter is selected to have a mechanical resonance that is approximately matched to the characteristic frequency.

27. The apparatus of claim 26 wherein the characteristic frequency of at least one of the band-limited signals is the central frequency of the frequency band that said at least one band limited signal occupies.

METHOD AND APPARATUS FOR ENHANCING THE SOUND QUALITY OF AN ULTRASONIC LOUDSPEAKER SYSTEM

ABSTRACT

A harmonic generator is used to generate harmonics of the lower frequencies in an audio signal. These harmonics and the audio signal are then modulated onto an ultrasonic carrier wave and are transmitted by ultrasonic emitters. The presence of the harmonics provides (upon demodulation) a psycho-acoustic impression of improved perception of low frequencies. Further, a modulated ultrasonic signal may be band-passed into two or more different band-limited signals. These band-limited signals are then amplified and transmitted by ultrasonic transducers having mechanical resonance frequencies substantially equal to a characteristic frequency of the band-limited signals. Still further, an unmodulated audio signal may be bandpassed into two or more different band-limited signals. These band-limited signals are then provided to separate ultrasonic modulators that have different carrier frequencies. The resulting modulated signals are then provided to ultrasonic emitters that have mechanical resonant frequencies substantially equal to a characteristic frequency of the respective modulated signals.

(Fig. 1)

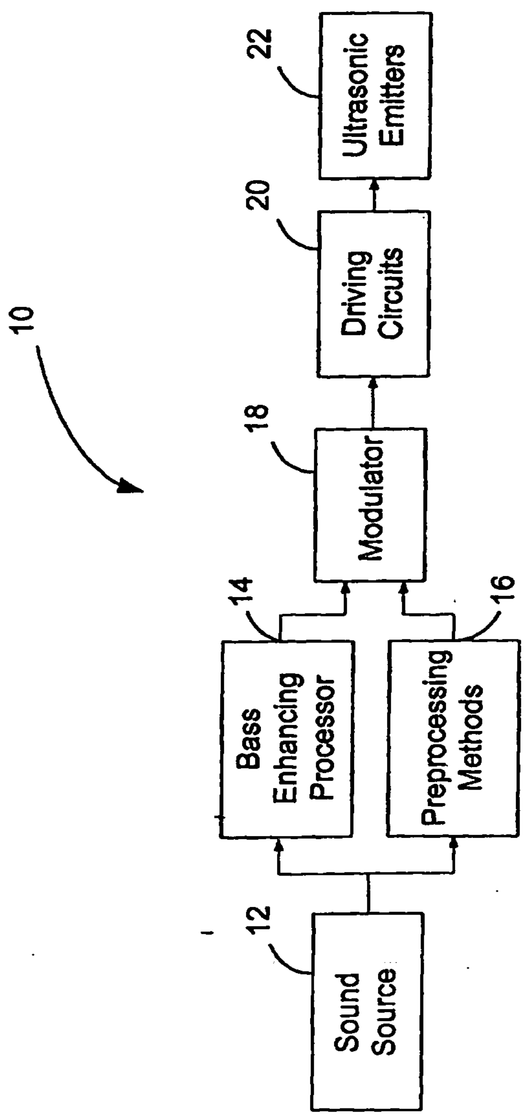
10
Sound Source
12
Bass Enhancing Processor
14
Preprocessing Methods
16
Modulator
18
Driving Circuits
20
Ultrasonic Emitters
22

FIG. 1

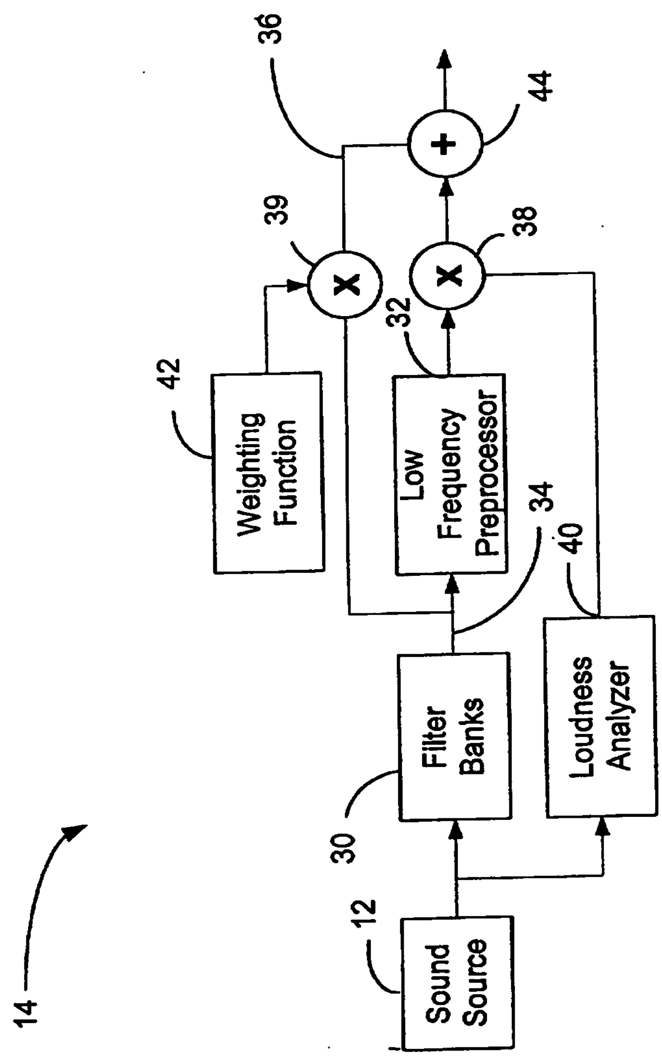
Sound Source
Filter Banks
Loudness Analyzer
Low Frequency Preprocessor
Weighting Function
14
12
30
34
40
32
42
39
38
36
44

FIG. 2

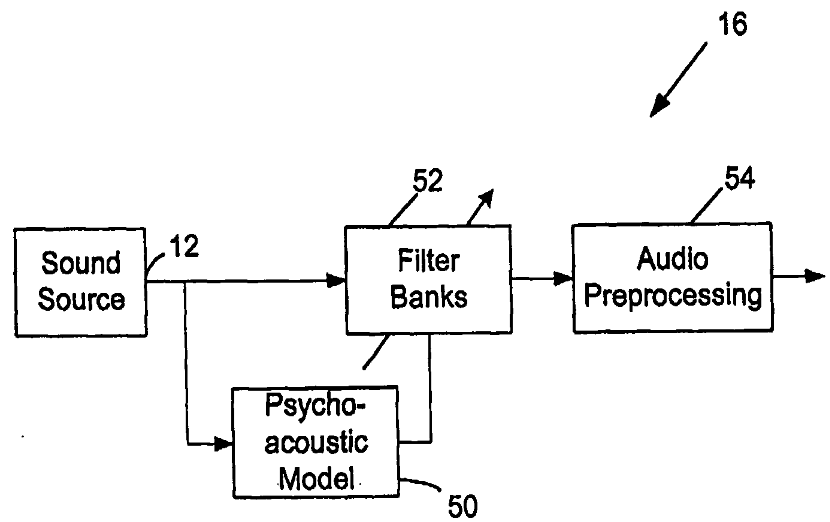
16
52
54
Sound Source
12
Filter Banks
Audio Preprocessing
Psycho-acoustic Model
50

FIG. 3

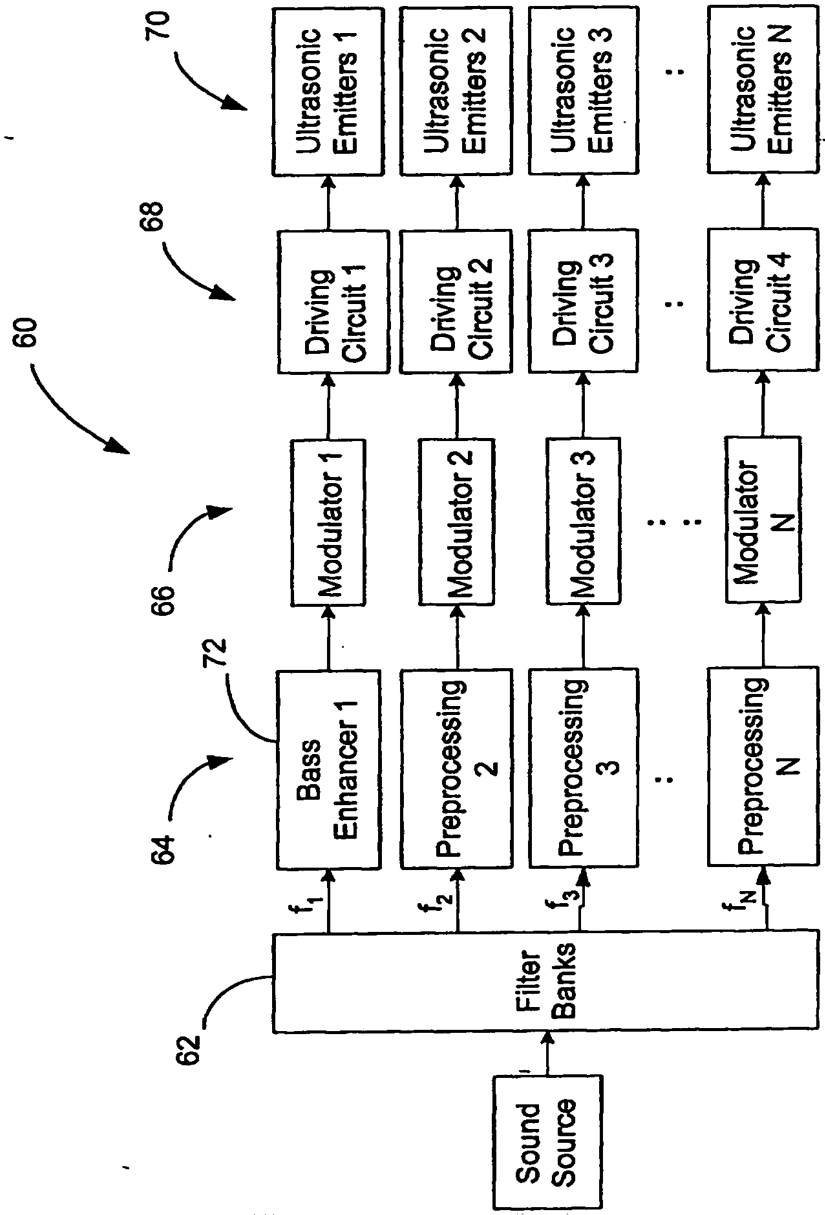
60
62
64
66
68
70
72
Sound Source
Filter Banks
f_1
f_2
f_3
f_N
Bass Enhancer 1
Preprocessing 2
Preprocessing 3
Preprocessing N
Modulator 1
Modulator 2
Modulator 3
Modulator N
Driving Circuit 1
Driving Circuit 2
Driving Circuit 3
Driving Circuit 4
Ultrasonic Emitters 1
Ultrasonic Emitters 2
Ultrasonic Emitters 3
Ultrasonic Emitters N

FIG. 4

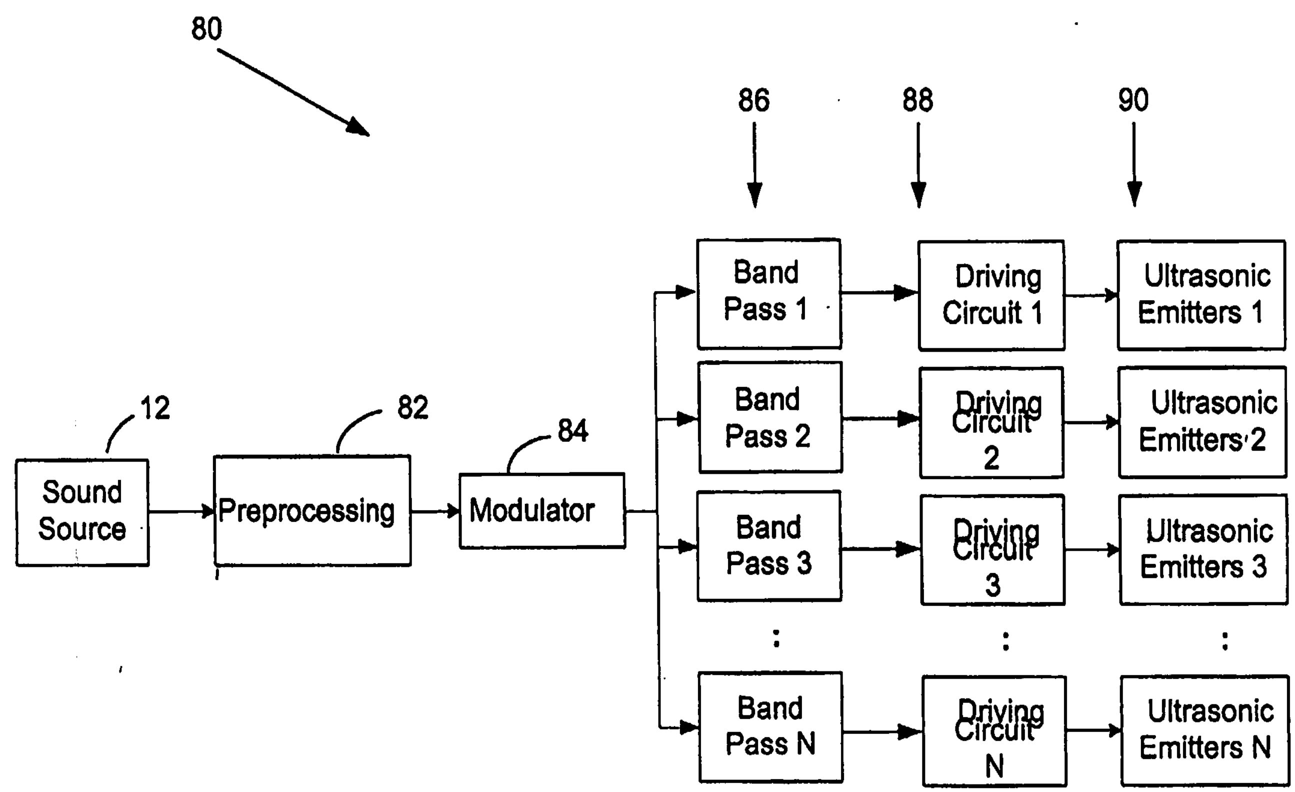
80
86
88
90
12
82
84
Sound Source
Preprocessing
Modulator
Band Pass 1
Band Pass 2
Band Pass 3
Band Pass N
Driving Circuit 1
Driving Circuit 2
Driving Circuit 3
Driving Circuit N
Ultrasonic Emitters 1
Ultrasonic Emitters 2
Ultrasonic Emitters 3
Ultrasonic Emitters N

FIG. 5